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SPUTTERING OF SILVER BY IONS OF NOBLE GASES

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ABSTRACT. Sputtering yields of silver in collision with the ions of noble gases at energies from 3-7 Kev were determined by tracer method Angular distribution of the sputtered atoms of silver was measured Results are discussed and compared with the existing theories.

INTRODUCTION

The studies of the phenomena of sputtering of the solid surfaces are of current interest, since it gives some ideas of the mechanism of the surface collision processes by energetic ions. Such studies of the metal surfaces are important for optimising the ion retention condition of a collector in an electromagnetic isotope separator and the use of the ions of noble gases gives informations about the improvement of the method of preparation of the gaseous isotopic targets, required in the experiments of nuclear physics.

Wehner (1955) has reviewed the results of the experiments on the sputtering by low energy ions. Moore *et al.* (1957), Brian *et al.* (1958), Grønlund *et al.* (1960), Rol *et al.* (1960), Yonts *et al.* (1960) and Wehner (1960) have given the results on the sputtering yield for energies below 100 kev and some of them present the angular distribution of the sputtered material Almen and Bruce (1961) have investigated various aspects of sputtering of metal by ions of noble gases as well as other ions in the light of the collection problems of the isotopes.

In the present paper, we have presented some preliminary results of the measurement of the sputtering yields of silver along with the angular distribution of the sputtered materials for ions of helium, neon, krypton and xenon at energies from 3-7 Kev.

EXPERIMENTAL METHOD

The system employed in the present experiment consists of a magnetic oscillation type arc discharge ion source with radial extraction arrangements with a 3/16″ diameter hole for extraction of the ions. The electronic circuits used in the experiment, are power supplies for the arc, filament and the accelerating voltage previously described by Karmohapatro (1960). The sputtering chamber with the silver-110m target and the ion source are shown in Fig. 1. 99-100% pure gases are introduced to the ion source. The number of ions, on the target, considered to be all as singly charged, was estimated by a current indicator and integrator. For each experiment with the different gases, the ion current was fixed at $\sim 10\mu A$ by varying the arc condition, to avoid unequal heating of the target, which might cause variations in the total yield. The sputtering chamber was kept at a pressure $\sim 10^{-5}$mm Hg in course of bombardment with the aid of a differential pumping arrangement.

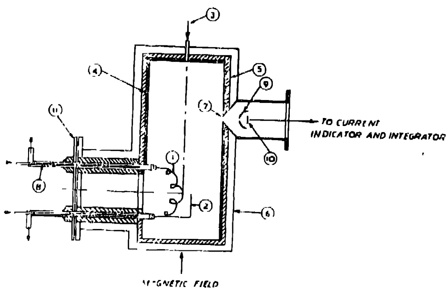

Fig 1. Schematic diagram of the ionsource and the sputtering chamber, (1) 40 mil dia tungsten filament, (2) molybdenum plate, (3) gas inlet and electrical lead for anode, (4) graphite anode, (5) electrical insulation (Eigan), (6) metal casing, (7) ion exit slit, (8) water cooling tubes, (9) collector of the sputtered atoms, (10) silver-110m target, (11) insulated flange for filament holders.

The total activity in the collector cup was measured with a $1\frac{1}{2}''$ diameter NaI crystal scintillation spectrometer. The counts for each collector give the relative sputtering yield for ions of different energy and mass. The sputtering yield, S, (atom per ion) at 5 Kev for neon ions, found by Grønlund *et al.* (1960) as 5.5, was normalised to that estimated by the radioactivity in our experiment. This value of S at 5 Kev is reasonable, when compared to 1.98 found by Laegried and Wehner (1961) at 600 ev. With respect to this absolute value, S was estimated for different ions of the noble gases of various energies in collision with silver surface.

The angular distribution was measured by the activity, with a Geiger counter, of the small pieces (1/16" dia) of the collector cup, cut uniformly in the radial direction.

In all cases, the target was bombarded by normally incident ions and after each bombardment the target was properly cleaned.

Since the sputtering chamber was within the magnetic field of the ion source itself, the number of the secondary electrons from the target was assumed to be negligible.

RESULTS

Fig. 2 shows the sputtering yield S as a function of the mass number of the noble gas ions in collision with silver. Figs. 3 and 4 show the energy versus yield curve for krypton and xenon ions respectively. Fig 5 is the polar diagram showing the angular distribution of the sputtered atoms for different ion masses at 5 Kev. Figs. 6 and 7 are the polar diagrams showing the angular distribution of the materials sputtered by different energy ions.

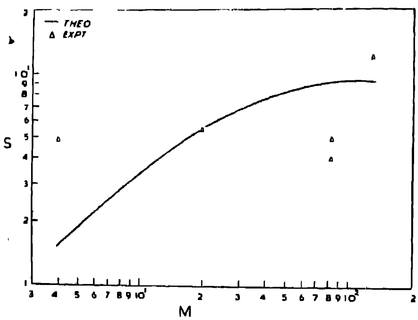

Fig. 2. Sputtering yield, S, as a function of mass of ion for normally incident 5 Kev ions on silver-110 m target.

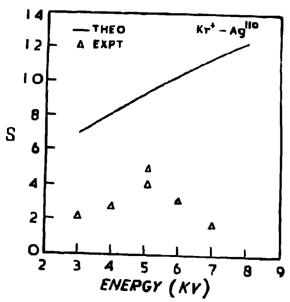

Fig. 3 Sputtering yield as a function of ion energy for krypton ions normally incident on silver-110 m target.

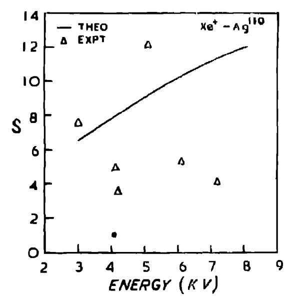

Fig. 4. Sputtering yield as a function of ion energy for xenon ions normally incident on silver-110 m target.

DISCUSSION

The theoretical models, explaining the sputtering process are mainly (1) the theory of evaporation and the (2) momentum transfer process.

The velocity of the sputtered atoms, determined by Wehner (1959), mass dependence of the sputtering yields found by many authors and in the present work, the ejection patterns of the sputtered atoms in the preferential direction of a monocrystal observed by Wehner (1955) and some other experimental results related to the sputtering phenomena cannot be explained by the evaporation theory.

The angular distribution of the sputtered materials measured by Seeliger and Sommermeyer (1935), Brian *et al* (1958) and Grønlund *et al* (1960) seems to follow cosine law, so that the evaporation theory is supported.

The results of our measurements of the angular distribution of the sputtered material with the ion energy and mass are presented in Figs. 5, 6 and 7. The polar diagrams sre drawn such that the enclosed areas in each diagram are propor-

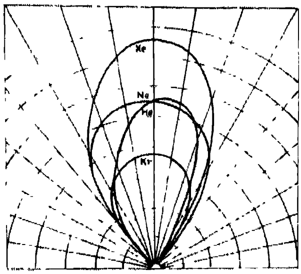

Fig 5 Polar diagram of material sputtered from silver-110 m by normally incident 5 Kev ions of helium, neon, krypton and xenon

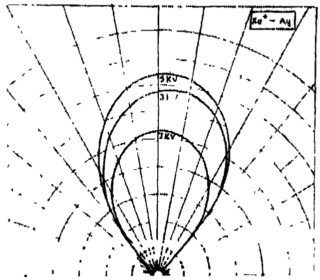

Fig. 6. Polar diagram of material sputtered from silver-110 m by normally incident krypton ions of different energies.

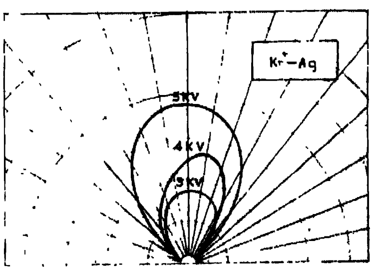

Fig. 7. Polar diagram of material sputtered from silver-110 m by normally incident xenon ions of different energies.

tional to the relative sputtering yields. The slight asymmetry with the normal in some of these curves is probably for deviation from the perpendicular incidence due to some mechanical misalignment of the collector

All the diagrams show that the angular distribution seems to be over-cosine in this energy range. This is in agreement with that found by Rol *et al.* (1960) for 20 Kv ions in copper or by Holmstron and Knight (1961) for argon ions in silver. For low energy ions the angular distribution is under-cosine, observed by Wehner *et al.* (1960). From all these findings it seems that depending on the energy and masses of the ions and the targets along with the orientations of a poly-crystalline target, the angular distribution is influenced, since in case of a mono-crystal, the sputtering prefers a closed packed direction of the crystal plane. However, considering all the observations the evaporation theory cannot explain the nature of change in the angular distribution of the sputtered materials.

It is difficult to compare the experimental results on the total sputtering yield S with the theoretical expectations, since the momentum theory, based on different assumptions and subject to modifications for different cases, cannot be applied in one form, but it indicates the nature of its dependence on the different parameters like mass, energy etc. In the light of the hard sphere collision model worked out by Keywell (1955), Thommen (1958), Pease (1958), Goldman *et al.* (1958), the mass dependence of the sputtering yield can be explained

Following the treatment of Rol *et al.* (1960), the sputtering yield is given by

$$S = K \cdot \frac{1}{\lambda} \cdot \frac{M_1 M_2 E}{(M_1+M_2)^2}$$

where K is a constant, M_1, M_2 are masses of the incident ion and the target, E is the energy of the incident ions. The mean free path

$$\lambda = \frac{1}{\pi R^2 n_0}$$

where n_0 is the number of lattice atoms per unit volume and the collision radius

$$R = C \cdot \frac{a_0}{(z_1^{2/3}+z_2^{2/3})^{\frac{1}{2}}} \; ln \; \frac{z_1 z_2 e^2 (M_1+M_2)}{\epsilon_0 \, REM_1}$$

as given by Seitz *et al.* (1956), swhere C is a constant, ϵ_0, the dielectric constant in vacuum, a_0, the first Bohr radius in hydrogen atom, e, the elementary charge, z_1 and z_2 are the atomic numbers of the incident ion and the target.

With a simple assumption that the sputtering happens in the first collision, the above expression is worked out. Assuming this model to be valid for the present energy range, we calculated the values of S for ions of different masses and energies. In calculating the theoretical values of S the value of K was chosen to give the best agreement with the experimental value ($= 5.5$) for 5Kv neon in silver, found by Grønlund *et al.* (1960) With this value of K, the values of the sputtering yields of silver, bombarded with ions of noble gases as a function of energy and masses of ions are shown in Figs. 2, 3 and 4. The comparison shows that the agreement is better for Xe^+ than Kr^+ in silver. The general discrepancy may be due to (1) a multiple collision process instead of the single collision approximation used in the theory, (2) the deviation of the value of K as shown by Almen and Bruce (1961) from a constant one, approximated in the above theory The major disagreement between the experimental results and the theoretical expectations lies in the fact that the value of S for krypton ions is relatively lower than that for neon ions, secondly, the maximum near 5 Kev in the sputtering yield versus ion energy for krypton and xenon ions cannot be explained with this model. The maximum near 5Kv with silver bombarded by helium and neon ions, observed by Grønlund *et al* (1960) is similar to our observations for xenon and krypton ions. For nitrogen and neon in collision with copper, Rol *et al*, (1960) have found a maximum for S near 15 Kev The maximum may be explained by the two opposite effects of the increasing energy, one of which increases the probability and the other increases the mean free path, thus reducing the probability of collision. Then the nature and position of such maximum will depend upon the target material and the bombarding ion. From the few experimental results observed so far, such dependence cannot be uniquely established The lower value of S for krypton ions as compared with neon ions in collision with silver surface also cannot be explained with the theory discussed above. Further examinations of more such data may be helpful for understanding the process in more detail.

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